Typical equilibrium coke.

A.P.I. SESSION ON REFINING PROCESSES

Continuous-Coking Process Shows Ability to Handle Heavy Feed Stocks

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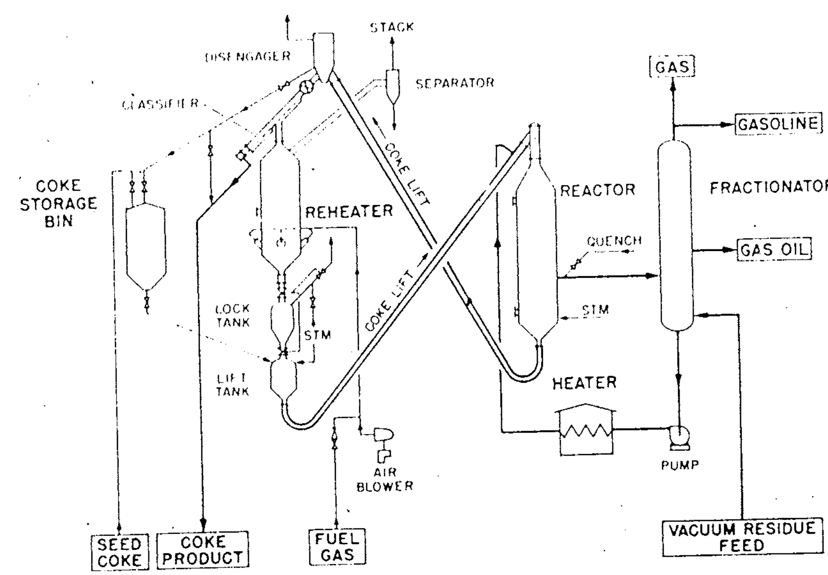

Fig. 1—Simplified flow diagram of 1,000-bbl. per day contact coking unit.

THE continuous-contact coking process has now been tested in commercial operation, and results show that the following advantages accrue from its application:

- Heavier residues than those normally handled by the conventional delayed coking method can be upgraded.
- Flexibility of the process permits processing stocks of widely different characteristics to obtain wider ranges of yields and product specifications.
- Need for intermittent cleaning of coke drums is eliminated.
- Product coke is clean, hard, uniform in size, and easily handled and marketed.
- Capital investment and operating labor for a contact unit are less than for a delayed coking unit.

The first commercial continuous contact coking unit was erected in the McKee refinery of Shamrock Oil & Gas Corp., Sunray, Tex. It was designed to process vacuum-distillation residue from Panhandle crude oil—at a nominal charge rate of 1,000 bbl. per day—for the production of gas, gasoline, gas oil for catalytic cracking feed, and coke.

The unit has been in operation for the past 8 months, during which period yields over a wide range of operating conditions were obtained. The outstanding feature of the unit is its flexibility and ability to handle feed stocks much heavier than normally can be processed by conventional delayed coking.

Data on yields, product specifications, and operating costs are presented herein.

Development . . . The development work on the continuous-contact coking process has been carried out during the past 6 years, and was described in earlier publications.[1,2,3] This work was accomplished with: (1) a laboratory unit; (2) a 50-bbl. per day pilot unit, followed by (3) a 100-bbl. per day semi-commercial unit; and, finally, (4) the commercial unit described in this paper. Yield correlations between laboratory unit and the commercial unit have been established. The laboratory unit now is used to evaluate any stock with reasonable confidence.

Description of Unit

Fig. 1 is a simplified flow diagram of the 1,000-bbl. per day unit.

The unit consists essentially of: (1) a reactor in which the oil-wetted coke particles or "seed" coke flow downward as a dense bed; sufficient time is provided in the reactor for the cracking, coking, and drying reactions; (2) a re-

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heater in which the circulating coke is raised in temperature to supply the heat of reaction, some sensible heat to the feed, and radiation losses; (3) a coke-circulating system which uses the "mass-flow" principle to elevate the coke as a dense unagitated column; and, (4) a fractionation system for the separation of products.

The vacuum-residue feed is introduced into the bottom of the fractionator, where it is mixed with recycle stock and further preheated in a tubular heater to approximately 700° F. This feed is mixed thoroughly with the hot circulating coke stream. The lighter portions of the feed are vaporized, and the heavier constituents are retained on the coke particles as a liquid film. As the coking reaction proceeds, the film is converted into gas, hydrocarbon vapors, and residual coke, and the latter is retained on the seed particle.

As successive increments of coke are deposited, a gradual increase in coke-particle size occurs. The larger particles, which have a diameter of approximately ½ in. or more, are drawn off continuously as product coke to maintain a nearly constant coke inventory in the system. The vapors from the reactor, at a temperature of 900° to 1,000° F., are quenched and released to the fractionator. From the bottom of the reactor the dried coke is elevated to the disengager by a low-pressure mass lift which is "powered" by the reactor pressure of 35 psig.

The coke from the disengager flows by gravity into the reheater, where it is heated to between 1,000° and 1,100° F. by gas firing or by burning a portion of the coke. The reheated coke is discharged intermittently by gravity into the lock tank, from which it flows into the lift tank to start another cycle of the coke circuit. The energy for circulating the coke is supplied by 150-psig. steam at the lift tank. The sequence of coke flow from the reheater and lock tank is controlled automatically by a cycle timer.

This is the first commercial installation of the "mass-flow lift" developed by Union Oil Co. of California. The coke circulation is continuous and smooth. The rate of flow is controlled by a rotary star valve above the reheater. Only one coke level must be controlled—that of the reheater. The coke-circulation rate may be increased or decreased by varying the speed of the rotary star valve.

The ratio of oil to coke for normal operation is 10 bbl. of oil per day per ton of coke circulation per hour, i.e., 1 lb. of oil per 14 lb. of coke circulated.

The general arrangement of the unit and equipment is shown in Fig. 2. The highest elevation of any equipment is 80 ft. above grade. The reactor and reheater are supported from the third level above grade, with the blower and lift tank on a lower level. The control room is located at grade. Advantage

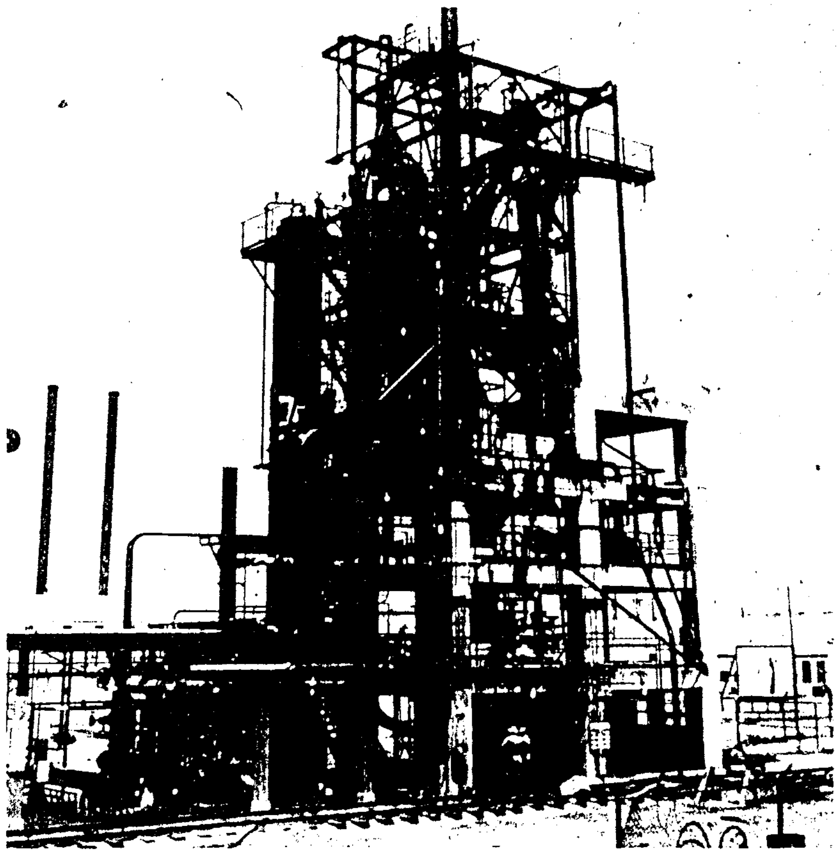

Fig. 2—General view of contact coking unit at plant of Shamrock Oil & Gas Corp., Sunray, Tex.

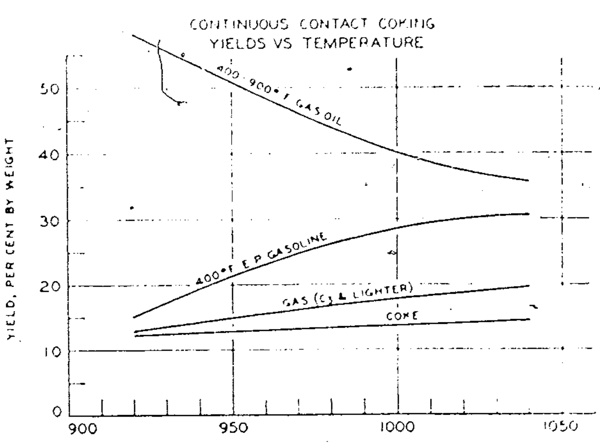

Fig. 3—Correlations of product yields vs. reactor temperature.

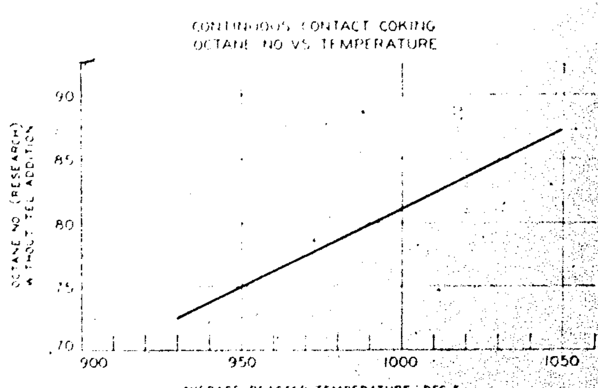

Fig. 4—Correlation of gasoline octane number vs. reactor temperature.

has been taken of the latest developments in automatic instruments for control of the coke-circulating system.

Performance . . . Table 1 presents feed-stock characteristics, operating conditions, yields, and product specifications of a typical run.

The feed stock to the unit was a vacuum-distillation bottoms from Texas Panhandle paraffinic crude oil, and represented approximately 10 per cent on the crude. This is a much heavier charge stock than normally could be processed by a conventional delayed-coking unit.

The products were metered and, wherever possible, tank gages were used. Coke production was determined by difference. Test runs under varying reaction temperatures were made. The unit operated successfully with average reaction temperatures as low as 900° F. and as high as 1,025° F.

Yields for a range of reactor temperatures are presented in Table 2.

TABLE 2—SUMMARY OF YIELDS WITH VARIOUS REACTOR TEMPERATURES

Test No.—	1	2	3	4
Average reactor temperature, °F.	1,025	985	965	955
Yields, per cent by weight—				
C_3 and lighter	18.6	17.1	15.8	14.5
C_4 to 400° F. Gasoline	29.9	27.2	24.0	22.0
Gas oil	37.5	42.2	47.2	51.0
Coke	14.0	13.5	13.0	12.5
Total	100.0	100.0	100.0	100.0
Research octane number, without TEL addition, A.S.T.M. D 908 (research method), corrected to 10 lb. R.v.p.	84.0	80.5	76.6	75.0

From our experience it is apparent that lower operating temperatures are practical, and could be attained by still further preheating of the feed stock to the extent that the heat of vaporization is supplied in a tubular heater and, thus, the coke temperature levels are reduced throughout. A reduction in temperature level will reduce the gas and gasoline production with a corresponding increase in the yield of gas oil.

Fig. 3 presents test-yield curves vs. reaction temperatures. These curves have been plotted from actual data obtained from approximately 50 runs with varying operating conditions. The trend of the curves for each of the products is similar to yields obtained from a delayed coking operation. Compared with delayed coking, the yields from contact coking show considerably lower coke production with higher gas and gasoline yields.

The important point, which is evident from these curves, is that the operating temperature range of a contact coker is much wider than can be obtained with a conventional delayed coker and, likewise, the product yields and specifications can be controlled over a wider range.

TABLE 1—PROPERTIES OF CHARGE STOCK, YIELDS, AND PRODUCT SPECIFICATIONS

	Texas Panhandle vacuum bottoms
Charging stock—	
Gravity, °A.P.I.	18.9
Material boiling at lower than 950° F., per cent by volume	2.0
Sulfur, per cent by weight	0.6
Conradson carbon, per cent by weight	11.7
Viscosity (Saybolt Furol) at 122° F., sec.	1,227
Characterization factor, U.O.P.	12.3
Per cent on crude	10.0
Operating conditions—	
Oil inlet temperature, °F.	690
Coke inlet temperature, °F.	990
Coke outlet temperature, °F.	915
Average reactor temperature, °F.	955
Reactor pressure, psig.	36
Mass lift—	
Coke circulation, tons per hour	75
Lift-tank pressure, psig.	130
Lift steam, lb. per hour	650
Yields, per cent by weight—	
C_3 and lighter	14.5
C_4 to 400° F. gasoline	22.0
Gas oil	51.0
Coke	12.5
	100.0
Inventory coke—Screen analysis—Per cent by wt. retained on screen: Tyler Screen No.	
0.25-in. mesh	49.0
4 0.187-in. mesh	21.4
6 0.131-in. mesh	13.8
8 0.096-in. mesh	12.6
12 0.065-in. mesh	1.8
18 0.039-in. mesh	0.9
Pan	0.5

Product inspection:	
Gas analysis, per cent by weight—	
Methane and lighter	18.1
Ethylene	11.1
Ethane	15.5
Propylene	25.4
Propane	3.3
Butane	13.0
Butylene	13.6
	100.0
Per cent olefins	50.1
Gasoline—	
Gravity, °A.P.I.	54.4
A.S.T.M. distillation, °F.:	
Initial boiling point	136
10 per cent point	202
50 per cent point	281
90 per cent point	362
End point	395
Research octane number:	
Without TEL addition	76.5
With addition of 3 ml. TEL per gal.	83.0
Characterization factor, U.O.P.	11.9
Aniline point, °F.	99.0
Sulfur, per cent	0.14
Gas oil—	
Gravity, °A.P.I.	27.5
Vacuum distillation, °F. at 760 mm.:	
Initial boiling point	400
10 per cent point	500
50 per cent point	760
90 per cent point	1,050
Characterization factor, U.O.P.	11.85
Coke—	
Bulk density, lb. per cu. ft.	64.0
Volatile matter, per cent by weight	3.7
Ash, per cent by weight	1.0
Sulfur, per cent by weight	0.6

Product Specifications

Fig. 4 presents the relationship between the octane number of the gasoline vs. average reactor temperature. For a reaction temperature of 950° F., the octane number, A.S.T.M. D 908 (research method), without TEL addition, is 75; whereas at a temperature of 1,025° F. the octane number is 84. The lead susceptibility of the gasoline is improved approximately 6 to 8 points with the addition of 3 ml. of TEL. Octane numbers of the gasoline produced on a delayed-coking unit from the same paraffinic stock will run 10 to 15 points lower.

A gas analysis is presented in Table 1. It will be noticed that the olefin production is approximately 50 per cent of the total gas. The corresponding yield of olefins from delayed coking is about 15 per cent. This concentration of olefins could be increased considerably by operation at higher coke temperatures. Some refiners will be interested in a maximum of gas production with high olefin content for chemical-plant feed stock. A pilot unit is presently in operation to investigate the high temperature levels for maximum production of olefins.

The specifications of the gas oil from the contact coking unit are similar to gas oil from the delayed coking unit when the same heavy stock is charged. Normally the charging stock to a delayed coking unit is a long reduced crude which contains a high percentage of virgin middle distillate.

The industry today requires, and in the future will require, higher yields

of middle distillates. Vacuum distillation carried to a heavy pitch produces a maximum of virgin distillate. The contact coker then provides a new tool to handle and convert the heavy pitch to gasoline and additional gas oil. Also the middle distillate, which normally is used as cutback to make marketable fuel oil of the vacuum bottoms, is then available for other uses.

Accompanying is a photograph of a sample of the equilibrium-coke inventory. The coke is of high mechanical strength, and withstands shock heating and cooling without noticeable fracture or failure. It is free-flowing, and has proved to be an excellent medium for supplying the required heat to the oil. The product coke is essentially spherically-shaped, and it is approximately ½ in. in diameter. It is harder and lower in volatile content than petroleum coke which has been produced in a delayed coker. The ash content and sulfur depend on the source of the feed stock. The product coke normally is suitable for electrode manufacture when calcined.

Process equipment . . . Because this unit represents a 10-to-1 increase in capacity over the 100-bbl. per day pilot plant previously operated, some "scale-up" factor problems could be expected. The novel features of the process equipment are the oil-coke mixing system, the mass-lift system, and the coke reheater. The mixing system required considerable time to obtain perfect performance. Fortunately, the final solution is one which readily may be extrapolated to much larger sizes.

The mass-lift operation was complicated by the radical difference in the characteristics of the petroleum coke used as "seed" and the equilibrium material obtained after startup. However, minor modifications resulted in satisfactory operation.

The coke-reheater capacity was somewhat inadequate, and could not be corrected fully without extensive changes to the original equipment. The reduced heat input to the coke has limited the oil-charge capacity.

Tests have shown that the other equipment is adequate for the design capacity. The unit also has operated satisfactorily at the design coke-oil ratio by reduction of the coke circulation. In a new unit the reheater deficiency can be corrected readily on the basis of data obtained during operation of this unit.

Investment and Operating Costs

Based on the experience with the 1,000-bbl. per day unit, there is under design a 2,500-bbl. per day unit which incorporates the modified mechanical features.

An economic comparison of a 2,500-bbl. per day continuous contact coking unit vs. a delayed unit has been prepared on the basis of charging Panhandle vacuum bottoms. These data are presented in Table 3. The comparison indicates that, at this capacity, the over-all economics favors the contact coking process.

When credit is allowed for the potential recovery of olefins in the product gas at a value of 3 cents per pound, the total differential profit is $2,171,280 per year. The corresponding figure for a delayed coking unit is $1,656,480 per year. The difference favors the contact coker by $514,000 per year.

The over-all operating labor required is considerably less for a contact unit. The coke drum turn-around labor, which normally consists of unheading, coke cleaning, and reheading of the drums, is eliminated. The unit is handled by two operators.

TABLE 3—COMPARISON OF CONTACT WITH DELAYED COKING—PROCESSING 2,500 BBL. PER DAY OF VACUUM BOTTOMS

	Contact process		Delayed coking process	
Unit—	Per cent by wt.	Per cent by vol.	Per cent by wt.	Per cent by vol.
Yields—				
Gas, C_3 and lighter	14.9		7.5	
Gasoline, C_4 to 400° F. e.p.	21.1	26.6	18.5	23.4
Gas oil	51.0	55.0	54.0	58.0
Coke	13.0		20.0	
Olefins in gas	50.1		15.1	
Utilities—				
Water, g.p.m.		1,600		2,200
Steam, lb. per hour		13,000		10,000
Fuel, million B.t.u. per hour		29		25
Electricity, kw.		50		50
Operating labor, men per shift		2		4
Investment, dollars		1,600,000		2,100,000
Direct charges, dollars per day —				
Raw material		2,500		2,500
Utilities		-417		363
Labor		108		216
Maintenance		110		130
Total charges		3,135		3,209
Value of products, dollars per day		8,151		7,765
Differential profit,* dollars per day		5,016		4,556
Differential profit,* dollars per year		1,655,280		1,503,480
Payoff,* months		11.6		13.9

Assumed Values of Charging Stock, Products, Utilities, and Labor

	Contact process and delayed coking process
Charging stock, dollars per bbl.	1.00
Products—	
Gas, cents per million B.t.u.	.29
Gasoline, cents per gallon:	
80 O.N.	11.75
64 O.N.	11.00
Gas oil, dollars per bbl.	3.00
Coke, dollars per ton	6.00
Utilities—	
Water, cents per 1,000 gal.	1.5
Steam, cents per 1,000 lb.	55
Fuel, cents per million B.t.u.	29
Electricity, cents per kw.-hr.	0.75
Labor (cost per hour), dollars	2.25

*Does not include taxes, insurance, amortization, interest, and royalties.

Summary

Continuous contact coking is a new process for the upgrading of heavier residues than normally can be handled by the conventional delayed coking method.

A continuous contact coking unit, in combination with vacuum flashing to a heavy pitch, will produce a maximum of middle distillate, and thus provide a new tool to assist in meeting the industry's need for higher yields of middle and light distillates.

The inherent flexibility of the process permits processing stocks of widely different characteristics and, by varying the operating conditions, a much wider range of yields and product specifications are obtained than heretofore possible.

The process is continuous, and thus eliminates the intermittent cleaning of coke drums and attendant expense.

The product coke is clean, hard, uniform in size, and easily handled and marketed.

The capital investment and operating labor for a contact unit are less than for a delayed coking unit.

Engineering designs for a 2,500-bbl. per day unit are now being completed.

References

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